THE FUNDAMENTAL ARC SERIES IN SODIUM AND ITS PRESENCE IN THE SUN

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY
IN THE UNIVERSITY OF MICHIGAN

BY
PAUL ROOD
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ABSTRACT

Using a powerful discharge tube of new design, the infrared arc spectrum of sodium has been photographed, and measured with a thermopile, as far as λ 12679, $3^2D-5^2F^\circ$. In addition to this line, five new members of the $^2D^2F^\circ$ series in *Na* I were measured with an accuracy of ±0.2 or ±0.3 A. Data supplied by Miss C. E. Moore and Mr. H. D. Babcock, of the Mount Wilson Observatory, indicate that this sodium series is present in the solar spectrum. New values for the $^2F^\circ$ terms are given. In addition, three members of the $4^2S-5^2P^\circ$ series were observed for the first time.

In connection with their program of identification of the infrared solar lines at the Mount Wilson Observatory, Miss Charlotte E. Moore and Mr. H. D. Babcock have called to our attention the fact that no recent or accurate measures are available of the Bergmann series in the arc spectrum of sodium. The approximate positions of the lines can be predicted within a few angstroms, but no values good enough for certain identification are known.

The first measurement in the sodium $^2D^2F^\circ$ series was made in 1907 by Bergmann,[1] who in his original work observed, but did not classify, the second member of the series. In the next year, both the first and second members were measured by Paschen,[2] who gave their wave lengths as λ 18459.42 ± 2. and λ 12677.54 ± 8. No other measurements in the fundamental series appear to have been made, although a calculated 6^2F° term has been obtained from a supposed $3^2P^\circ - 6^2F^\circ$ combination at λ 4665 and λ 4660. This term does not agree well with the one determined in the present work.

The successful measurement of the lines of the fundamental series requires a vacuum source, since in open arcs they appear broad and fuzzy, if they appear at all. The source finally found most suitable was the positive column in a large end-on discharge tube. The tube was of pyrex glass, 3 cm. in diameter and about a meter long, with large cylindrical aluminum electrodes in side arms. Pure redistilled sodium was introduced into the tube in glass boats, and the re-

[1] *Zs. f. Wiss. Phot.*, **6**, 113 and 145, 1908. [2] *Ann. d. Phys.*, **27**, 543, 1908.

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quired pressure of sodium vapor was produced by an electric furnace surrounding the tube. The discharge was carried by pure helium or neon. The series was more intense in helium; but the third and fifth members fell too close to helium lines for measurement, and a discharge in helium-free neon was used to obtain these lines. The helium or neon was circulated through charcoal traps in liquid air and through the tube by means of a glass mercury pump. Sixty-cycle current from a 2000-volt transformer at currents of 1 to 1.5 amperes, at suitable pressures of sodium and of the gas used, provided a very intense sodium light.

The intensity of the sodium spectrum in the discharge was sufficient to permit thermopile measurements in the infrared with a grating spectrograph. This instrument,[3] which was placed at our

TABLE 1

MEASUREMENT OF THE $3^2P^o-4^2S$ DOUBLET OF SODIUM

Classification	Wave Length Observed	ν	$\Delta\nu$ Observed	$\Delta\nu$ Calculated	Error
$3^2P^o-4^2S$.....	11403.2	8767.1	.....	.....	.....
$3^2P^o-4^2S$.....	11381.0	8784.2	17.1	17.2	0.1

disposal by Professor E. F. Barker, who assisted in its use, has mirrors of 100 cm focal length and a 1100 lines per centimeter grating. Using the helium line λ 10830.3 as a standard, the second member of the sodium fundamental series, $3^2D - 5^2F^o$, was measured as λ 12679.0 $\pm$ 0.5 A. The contour of this line was mapped, and its width was found to be not greater than the slit width of the spectrograph, an indication of the sharpness of the lines from this discharge. As a test of the accuracy of this measurement, the $3^2P^o - 4^2S$ doublet, whose separation can be calculated from known terms, was measured, with the results shown in Table 1.

The shorter members of the fundamental series were photographed with a Littrow-type flint-glass spectrograph having a dispersion, at 10,000 A, of about 70 A per millimeter. Eastman M, Q, and Z plates were used in the regions of their respective optimum sensitivities. The exposures ran from $3\frac{1}{2}$ to 5 hours. The helium

[3] Barker and Meyer, *Trans. Faraday Soc.*, **25**, 912, 1929.

or neon lines emitted by the discharge tube, depending on the gas used, were taken as standards, the values being those from the recent measurements at the Bureau of Standards.[4] For converting the wave lengths to wave numbers, the values for the dispersion of air by Meggers and Peters,[5] extrapolated above λ 10,000, were used.

The final values adopted for the fundamental series lines of sodium are given in Table 2. The $^2F^o$ term values and effective quantum numbers are also given.

TABLE 2

THE FUNDAMENTAL SERIES OF SODIUM, $3^2D - m^2F^o$

$3^2D = 12276.18$

Term	Wave Length	Wave Number	m^2F^o	N_{eff}
4^2F^o*	18459.5	5415.8	6860.4	3.9994
5^2F^o	12679.0	7884.8	4391.4	4.9989
6^2F^o	10834.4	9227.3	3048.9	5.9993
7^2F^o	9961.0	10036.4	2239.8	6.9995
8^2F^o†	9466.0	10561.2	1715.0	7.9991
9^2F^o	9154.7	10920.4	1355.8	8.9965
10^2F^o	8943.6	11178.1	1098.1	9.9966
11^2F^o	8796.	11366.	910.	10.981

* Paschen's value, not measured in the present work.

† Calculated term. Interference in both helium and neon.

With the exception of λ 8796, which appeared on only one plate, the lines were each measured on two to four plates. The consistency of the various values indicated a reliability of ±0.2 or ±0.3 A for these lines. A further direct check on the accuracy was given by measurements on three members of the $4^2S - m^2P^o$ series, whose wave lengths can be computed from their known terms, determined from very accurate measurements at shorter wave lengths. These lines were here observed for the first time. The comparison is given in Table 3.

Miss Moore and Mr. Babcock have supplied us with information

[4] Meggers and Dieke, *Nat. Bur. Stand. J. Res.*, **9**, 121, 1932, Meggers and Humphreys, *ibid.*, **10**, 427, 1933.

[5] *Bull. Bur. Stand.*, **14**, 698, 1919. See also Babcock (*Phys. Rev.*, **46**, 382, 1934) on a method for obtaining infrared wave numbers from Kayser's *Tabelle der Schwingungszahlen.*

on the closest solar line to each measured sodium line of the fundamental series and also its probable solar identification. This information is given in Table 4. It is evident that this sodium series appears in the solar spectrum.

TABLE 3

NEW LINES IN $4^2S-m^2P^o$ SERIES OF SODIUM

Classification	Observed	Calculated*	Error
$4^2S-5^2P^o$.....	10747.2	10747.3	0.1
$4^2S-6^2P^o$.....	8649.6	8650.0	.4
$4^2S-7^2P^o$.....	7809.4	7809.6	0.2

* The calculated value is the mean wave length of the doublet.

TABLE 4

THE FUNDAMENTAL SERIES OF SODIUM IN THE SUN

Term	Laboratory	Sun			
	Wave Length	Nearest Solar λ	Int.*	Solar λ *minus* Lab. λ	Solar Ident.
4^2F^o†.....	18459.5	Too far out			
5^2F^o.....	12679.0	80.40	$6\underline{N}$	+1.4	$\underline{Na}$
6^2F^o.....	10834.4	34.01	$\underline{5}$	−0.4	$\underline{Na}$
7^2F^o.....	9961.0	61.38	$\underline{0}$	+0.4	*Na*
8^2F^o‡.....	9466.0	65.98	$-3?$	−0.0	*Na*
9^2F^o.....	9154.7	54.122 55.4	$\underline{-1N}$ $\underline{7}$	−0.6	$\frac{\text{Atm.}}{\text{Atm.}}$ *Na?*
10^2F^o.....	8943.6	43.058	$\underline{1}$	−0.5	*Fe*
11^2F^o.....	8796.	96.491	$\underline{1}$	+0.5	*Fe*

* Underline denotes that estimated intensity is from more than one plate.
† Paschen value of wave length.
‡ Wave length calculated.

We are much indebted to Dr. H. G. Beutler for aid in the distillation of the sodium and in the design of the tube, to Professor E. F. Barker for his co-operation in the infrared grating measurements, and to Miss C. E. Moore and Mr. H. D. Babcock, who instigated this work and supplied the solar data.

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